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ABSTRACT

One of the processes supposed to take place during development toward medical expertise is knowledge encapsulation. In this process detailed biomedical concepts are gradually clustered together and reorganized under fewer, clinically relevant terms. A large-scale investigation was made of the process of biomedical knowledge application using subjects of expertise level not too far apart to enable a more detailed analysis of the developmental path. Data indicate that the process of encapsulation is not as smooth as hypothesized. In the first year of the 2-year clerkship period a sharp decrease in the application of biomedical knowledge was observed. Two hypotheses to explain this phenomenon were explored but neither of them could explain the results. However, the finding that the first clerkship year results in a dip in clinical reasoning is a consistent finding and some educational and practical differences that may contribute to this finding are discussed. Three tables and five figures of data are included. (Author/JRH)

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The shock of practice; effects on clinical reasoning[1]

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Abstract

One of the processes supposed to take place during development toward medical expertise is knowledge encapsulation (Schmidt, Norman & Boshuizen, 1990). In this process detailed, biomedical concepts are gradually clustered together and reorganised under fewer, clinically relevant terms. Knowledge application (in real or simulated cases) is supposed to play a key role in this process. The present large-scale investigation (employing a think-aloud methodology) suggests that this encapsulation process is not as smooth as hypothesised. In the first year of the two-year clerkship period a sharp decrease in the application of biomedical knowledge is observed. Two hypotheses explaining this phenomenon have been explored: switching between biomedical and clinical knowledge bases as suggested by findings of Custers (1995) and output editing. None of these hypotheses can explain the results, and another one focusing knowledge tuning has been proposed. Since so far no further results are available that can be used to verify/falsify this hypothesis, a satisfying explanation for the outcomes is still lacking. However the finding that the first clerkship year results in a dip in clinical reasoning is a consistent finding and some educational and practical differences that may contribute to this finding are discussed

Introduction

Traditionally medical education consists of a preclinical and a clinical part. In the clinical part students are expected (to learn) to apply the biomedical and clinical knowledge they have gathered in the previous period. Theoretically this knowledge should be sufficient for the new task students have to face during the clinical rotations; in practice students often experience that they may have the right knowledge but that it is not readily available and is not available in a way that guarantees flexible application. During and through practice their performance improves.

Schmidt, Norman and Boshuizen (1990) have hypothesised that through the application of detailed biomedical knowledge in clinical reasoning a gradual subsumption of biomedical knowledge under higher order clinical concepts takes place. This process was termed "encapsulation"; it would lead to a decrease in the number of biomedical concepts in clinical reasoning, to abbreviations in the reasoning paths and to a better theoretical, biomedical underpinning of the clinical concepts applied that would be found in more experienced subjects.

Confirmation of this hypothesis was found in research by Van de Wiel, Schaper, Boshuizen, and Schmidt (1995). They investigated the biomedical ground of clinical concepts more or less commonly used indeed by asking subjects with different levels of experience to explain what was meant by X or Y, e.g. by uremic complaints, portal hypertension or ascites. Subjects were fourth-year medical students who had completed the preclinical period, fifth-year students after completion of the three-month internal medicine clerkship, and experienced internists. The encapsulation hypothesis was supported by their data: Van de Wiel et al. could show that the amount of biomedical knowledge covered by these concepts gradually increased over the years.

More support can be found in results of Boshuizen and Schmidt (1992), who asked medical students and experts to diagnose a case while thinking aloud. Subjects were second-year, fourth-year, and fifth-year medical students and experienced family physicians. They found that indeed the reasoning paths are abbreviated by medical experts. Especially fourth year medical students used very detailed reasoning steps.

Schmidt and Boshuizen (1993) investigated the application of biomedical knowledge by asking subjects of different levels of expertise to explain the process that had caused the

medical problem described in a clinical case. Subjects were health sciences students, second-year, fourth-year, and sixth-year medical students, and experienced internists. The number of biomedical concepts applied in the explanations showed an inverted U-formed relation with expertise level: The number of biomedical concepts applied by the students increased with increasing expertise levels, while experienced physicians used less, and less detailed, biomedical concepts to explain the case. This finding suggests an initial increase in biomedical knowledge, followed by an of this knowledge encapsulation under clinical concepts.

However, there are also indications that the process of knowledge restructuring is not as gradual as the encapsulation theory predicts. For instance, Custers (1995) asked students and experts to describe 20 diseases to him. His subjects were fourth-year and sixth-year medical students, interns in training as family physicians and experienced family physicians. Half of the subjects were asked to describe the clinical picture, while the other subjects were asked to describe prototypical patients having that disease. The reason for these two different questions was that Custers wanted to investigate if subjects describing prototypes would volunteer more information about the kind of patients afflicted by that specific disease; furthermore, he expected that experienced physicians who had seen more patients during their professional careers would 'benefit' more from the prototype instruction, which was not the case. For the present study another outcome regarding the number of biomedical concepts in the descriptions is more interesting. Not only did he find that increasing levels of expertise seemed to be associated with a decrease in the number of biomedical concepts applied, he also found that subjects of intermediate levels of expertise (advanced students and to a lesser degree the interns) were strongly affected by the kind of question asked. When these subjects were asked to describe the clinical picture of a disease much more biomedical concepts were used then in case they describe prototypical patients. Expert and novice protocols did not show these discrepancies. These findings suggest that at the intermediate levels of expertise, students switch between bodies of biomedical and clinical knowledge rather than that they use one integrated knowledge base. Novices don't switch, probably because they do not have multiple knowledge bases; experts don't switch because their biomedical and clinical knowledge is highly integrated and hence accessible by a multitude of stimuli.

Another indication that the shift from biomedical to clinical reasoning is not so gradual as expected, is given by the results found by Boshuizen and Schmidt (1992), who used second-year, fourth-year, and fifth-year medical students and experienced family physicians.

Their results suggest that fifth-year medical students (shortly after they have entered the clinical clerkships) apply hardly any biomedical knowledge in think-aloud, clinical reasoning tasks. This finding can be interpreted as an adaptation to their clinical environment where long detailed lines of reasoning are not encouraged. However, the biomedical knowledge applied in the post hoc explanations of the case did not show a corresponding dip. Therefore, this discrepancy might again indicated that students at this stage switch knowledge bases depending on the perceived task demands.

The latter two findings suggest that the observed discontinuity in the building up and encapsulation of biomedical knowledge is triggered by entering the clinical clerkships. A problem with this conclusion is however that both these experiments employed groups that were quite far apart in levels of expertise; either fourth- and fifth-year students or fourth- and sixth-year students were used plus one or two post graduate groups; Boshuizen and Schmidt (1992) used quite small numbers of subjetcs. The present experiment is meant to investigate the process of biomedical knowledge application using subjects of expertise levels that are less far apart, hence enabling a more detailed analysis of the developmental path.

Method

30 fourth-year and 24 fifth-year medical students at the University of Limburg, the Netherlands, were invited to participate. The study was conducted in the last trimester of the academic year. So the fourth year students had nearly finished their preclinical training, while the fifth year students were half-way their clerkship programme[2]. Subjects were recruited for a follow-up study; they were asked to participate in one session this year and a future session one year later. Indeed most students participated twice; only one fourth-year student could not be contacted, while two fifth-year students were not available for the second session. By doing so data of 30 fourth-year, 53 fifth-year and 22 sixth-year medical students could be collected. Furthermore, a reference group of a sample of 16 experienced physicians (gynaecologists) was included.

In the first session, subjects were asked to diagnose two clinical cases while thinking aloud. The cases (an anaemia case and a menstrual disorder case) were presented on cards (one item per card). Presentation order was balanced across subjects. In the next session two

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[2] The University of Limburg has a six year curriculum consisting of four pre-clinical and two clinical years.

parallel cases were presented, again balanced over subjects. The four cases were also balanced over the two session (see Table 1). After having diagnosed a case, the subjects were also asked to explain the pathophysiological process underlying the signs and symptoms in the case. The results of this part of the study have been reported earlier (Boshuizen, 1994)

Insert Table 1 about here

Balancing cases across sessions has the inherent hazard that the content of the cases becomes well known among the participating students. For the purpose of this study this risk was considered less serious than the interpretation problem that would result from using different cases in the subsequent session. In that case any difference found could be due to knowledge accretion or restructuring as well as to different case characteristics

Due to equipment failure and time available per session many subjects did not generate the four protocols that could be expected. In this way 184 analysable protocols were gathered: 59 produced by fourth-year students, 66 by fifth-years, 43 by sixth-years and 17 by medical specialists.

The analysis of the think-aloud protocols aimed at the identification of those parts of the protocols in which biomedical knowledge was applied in diagnosing the case. The identification of these parts was achieved in a step by step procedure. The first step was segmentation, based on pauses in the protocols. Next, general comments and meta-statements were removed. Examples are: "Oh Gee, That is difficult" or "I think I still have a lot to study." The segments thus remaining could be considered to be knowledge application statements and were rewritten as propositions consisting of a relation and a set of arguments, such as "contraception: condoms INDICATES does not use the pill". Finally the number of different biomedical concepts in the protocols were counted. These could concern pathological principles, mechanisms or processes underlying the manifestations of disease, e.g. terms referring to viruses, bacteria, stones or carcinomas or to tissue, organs, organ systems, or body functions (Patel, Evans & Groen, 1989). Thus an inter-rater agreement of .95 was obtained. When raters disagreed items were discussed. If no agreement could be reached, the items were classified as 'clinical'. Finally the auxiliary lines of reasoning were identified. These are (strings of) propositions where subjects activate knowledge about the normal situation or the normal process before running a mental simulation of a disorder in this situation or process. The utterances, propositions, biomedical propositions and auxiliary lines of reasoning were counted. The quality of the diagnosis was measured on a 4-point scale (0-3).

Due to the considerable number of missing values, data were analysed using a two-way Analysis of Variance with Expertise level and Cases as independent variables. Group differences were tested with a Student-Newman-Keuls test at the 5% level.

Results

Figure 1 shows an increase in the accuracy of the diagnosis $F(3,178) = 18.110, p < .0001$. Experts had better diagnoses than sixth-year students who had better diagnoses than fifth-year students and so on. All groups differed significantly, except the fourth- and the fifth-year students. There was a significant case effect, $F(1,178) = 10.853, p = .0012$, with better results for the anaemia case.

insert Figure 1 about here

The extent of the protocols also varied with expertise level, $F(3,178) = 5.222, p = .0018$ (see Figure 2). Fourth-year students generated more extensive protocols than the other groups, while the fifth-year students produced the least extensive protocols, followed by the experts. These differences between fourth-year students and the two other groups were statistically significant. Furthermore, a case effect was found, $F(1, 178) = 40.305, p < .0001$. The think-aloud protocols of the anaemia cases were more elaborate than the menstruation case protocols.

insert Figure 2 about here

The number of knowledge application propositions, $F(3,178) = 4.984, p = .0024$ (Figure 3) varied significantly with expertise level. Again fourth-year students generated more propositionsa than all other groups, while fifth-year students generated less propositions than the adjacent groups. Differences between the fourth-year students and the specialists and between the fourth- and fifth-year students were significant. A significant case effect was found, $F(1,178) = 34.895, p < .0001$, the protocols of the anaemia case containing more propositions.

insert Figure 3 about here

The number of biomedical concepts used in these propositions, $F(3,178) = 4.972, p = .0024$ (Figure 4), also varied in the same manner as the extent of the protocols. Fourth-year medical students used most biomedical concepts, the protocols of the fifth-year students showed a serious dip in this respect, but only the difference between fourth- and fifth-year

students was significant. Regarding biomedical concepts no differences between the two cases could be found, $F(1,178) = .008$, $p = .9269$.

insert Figure 4 about here

Finally, the number of auxiliary lines of reasoning (Figure 5) showed a significant effect, $F(3,178) = 3.540$, $p = .0159$. Contrary to fourth-year medical students, fifth-year students and more experienced subjects rarely applied such reasoning steps. Group differences were not significant. The effect of cases on the number of auxiliary reasonings was only marginally significant at the 10% level, $F(1,178) = 3.119$, $p = .0791$.

insert Figure 5 about here

Discussion

The aim of this study was to investigate if the sharp decrease in the application of biomedical knowledge in earlier studies (Boshuizen & Schmidt, 1992) should be attributed to a discontinuity in the knowledge accumulation and encapsulation process. Another study that suggested such a discontinuity (Custers, 1995) had suggested that this discontinuity might be the expression of a knowledge application strategy applied by subjects of intermediate levels of expertise in which they switch from one knowledge base to another (e.g., from a clinical to a biomedical) depending on the task demands. Experienced physicians might not show this strategy because their biomedical and clinical knowledge is fully integrated.

A first remarkable finding of the present study is that it mainly replicates the outcomes obtained earlier, i.e. a sharp decrease in the application of biomedical knowledge in fifth-year medical students. Given the large number of subjects and the fact that the same outcome has been found earlier with a different case and with subjects of partly different levels of expertise (but with the fourth- and fifth-year students we have employed here as well) we must conclude that it is a consistent finding. Critics of this outcome had earlier proposed that this finding that fifth-year students, who have recently started their clinical rotations, adjust themselves to the norms of the clinic (the faster and shorter an answer is, the better) and hence suppress long detailed lines of reasoning. The objection at that time to this 'output editing explanation' of the finding was that the protocols were obtained in a situation very different from the daily clinical work and that a think-aloud instruction rather encourages

verbosity. It can now be extended with the observation that it is a consistent finding and that the protocols of the sixth-year students are more extensive than their fifth-year student colleagues'. And there is no ground for assuming that the sixth-year students have less reason to suppress detailed reasoning; on the contrary, they might have even better adapted to the clinical situation.

Given the sharp decrease in biomedical concepts applied in clinical reasoning, the hypothesis of knowledge encapsulation as a continuous process due to knowledge application in (practical) clinical cases probably cannot be sustained. The alternative hypothesis that students at this level of expertise switch between knowledge bases that only later become integrated has to be contemplated. However, so far the further evidence that can be found in this study is not unequivocal. Indeed, as expected, the application of auxiliary, biomedical lines of reasoning indeed decreases after the fourth year: fifth-year students and more experienced subjects hardly ever use this kind of reasoning. However, if fifth- (and sixth-) year students would switch knowledge bases, then not only the number, but also the proportion of biomedical concepts in their think-aloud protocols should sharply diminish. This is not the case: the mean proportion of biomedical concepts in these protocols is about .15, $F(3, 178) = .729$; $p = .5357$. The standard deviations are largest for the fifth-and sixth-year students, suggesting that some fifth- and sixth-year students proceed applying biomedical knowledge, while others do not. This finding could be in favour of the switching hypothesis. However, the outcome that fifth-year students produce the shortest protocols does not fit very well with the idea that they use one of two knowledge bases that are still building up.

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insert Table 3 about here

These analyses give the impression that fifth-year students are facing another kind of 'crisis' in their learning process. Their diagnoses are not better than those given by fourth-year students, their post hoc explanation are not better, although they become less detailed and more coherent (see Boshuizen, 1994). Maybe this is also the case with the knowledge applied during clinical reasoning, but so far the protocols have not been analysed in such detail. For the moment it seems that the fifth-year students have lost their innocence: the long protocols in which much knowledge is activated in order to diagnose a case have disappeared and instead we see short protocols in which less biomedical *and* less clinical knowledge is activated. If neither lack of integration of knowledge bases nor output editing can explain this

finding, then maybe a lack of tuning of the knowledge to the reality of clinical everyday life can be the cause of the discontinuity observed. However, more detailed analyses of the think-aloud protocols and of the post-hoc explanations (especially in terms of quality and coherence) is required before such conclusions can be made.

Regardless of the reason for the cognitive discontinuity observed, it is a phenomenon that should alert clinical teachers. If students, during this phase of their training, are not well able to activate relevant knowledge, then the educational practices in the clinical and preclinical periods should be scrutinised. The sharp contrast between these two stages in their training, even in the problem-based curriculum of the University of Limburg (cases and simulated patients vs. real patients; ample time vs. time pressure; peer group setting vs. hierarchical setting; no responsibility for patients vs. some responsibility; etc.), might be the cause. A more gradual change, with more practical experiences in the preclinical phase and more problem-based tutorials in the clinical phase might help students to bridge this gap.

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Table 1. Cases used during the subsequent sessions for the different subjects

year 1	subj 1	Anaemia A	Menstr A
	subj 2	Menstr A	Anaemia A
	subj 3	Anaemia B	Menstr B
	subj 4	Menstr B	Anaemia B
	subj 5	Anaemia A	Menstr B
	subj 6	Menstr B	Anaemia A
	subj 7	Anaemia B	Menstr A
	subj 8	Menstr A	Anaemia B
year 2	subj 1	Menstr B	Anaemia B
	subj 2	Anaemia B	Menstr B
	subj 3	Menstr A	Anaemia A
	subj 4	Anaemia A	Menstr A
	subj 5	Menstr A	Anaemia B
	subj 6	Anaemia B	Menstr A
	subj 7	Menstr B	Anaemia A
	subj 8	Anaemia A	Menstr B

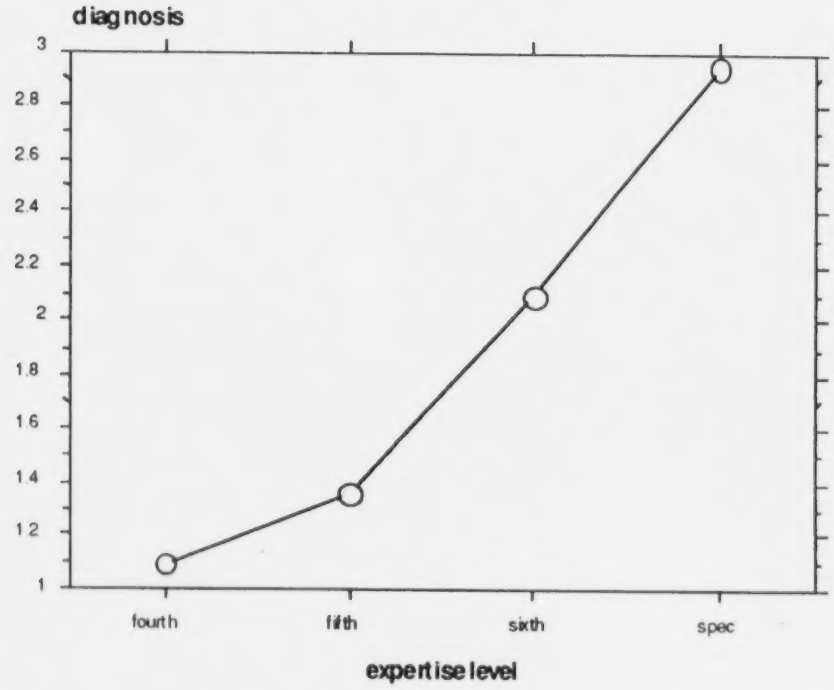

Figure 1. Diagnostic accuracy of subjects of four expertise levels.

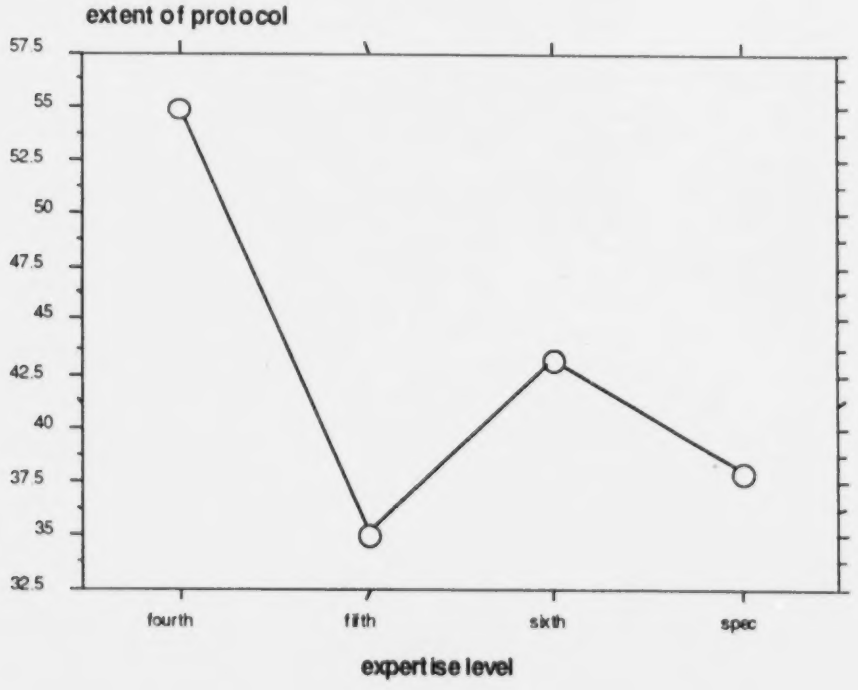

Figure 2. Extent of the protocols (number of utterances) generated by subjects of four levels of expertise

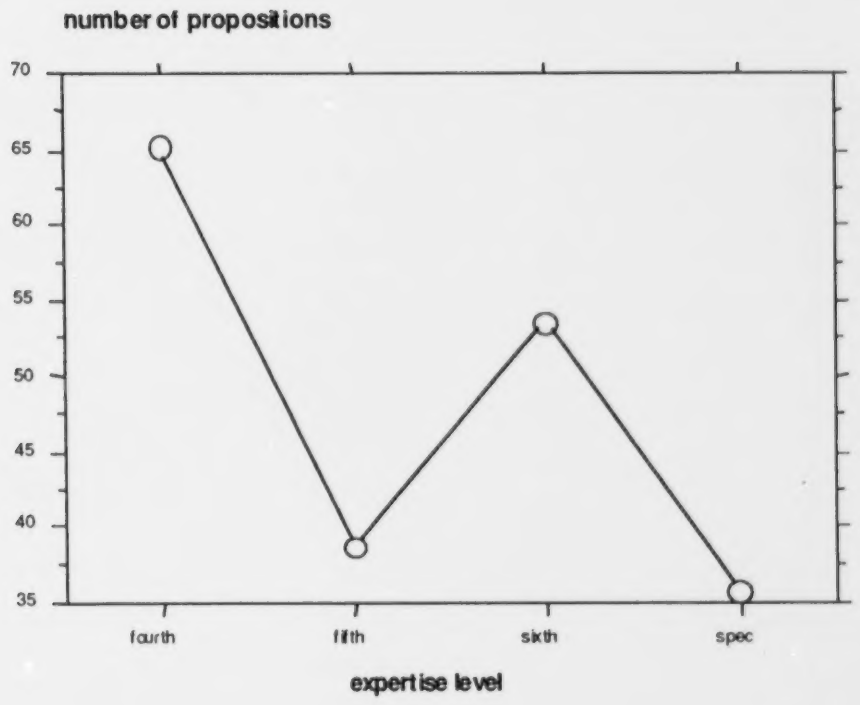

Figure 3. Number of knowledge application propositions

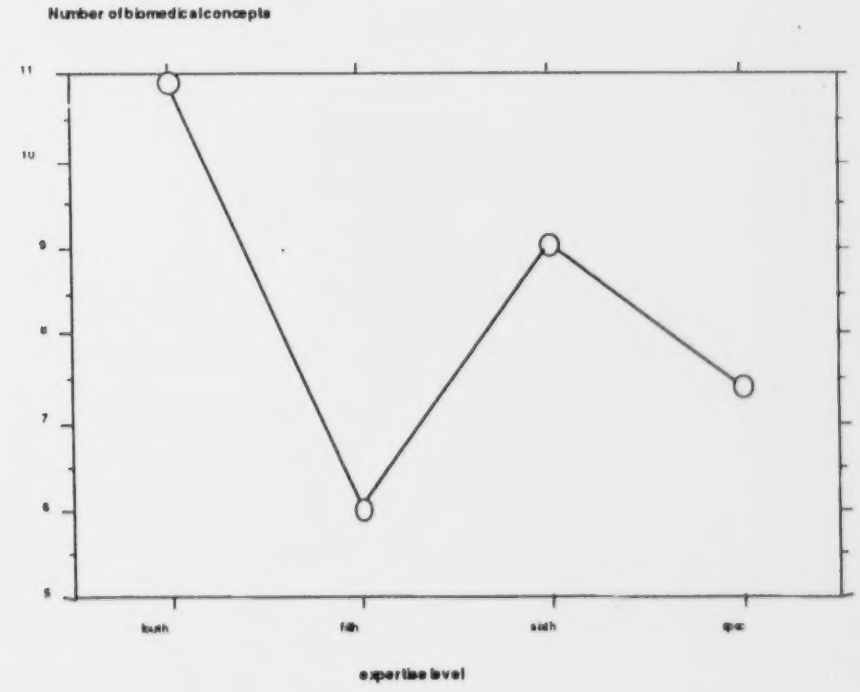

Figure 4. Number of biomedical concepts

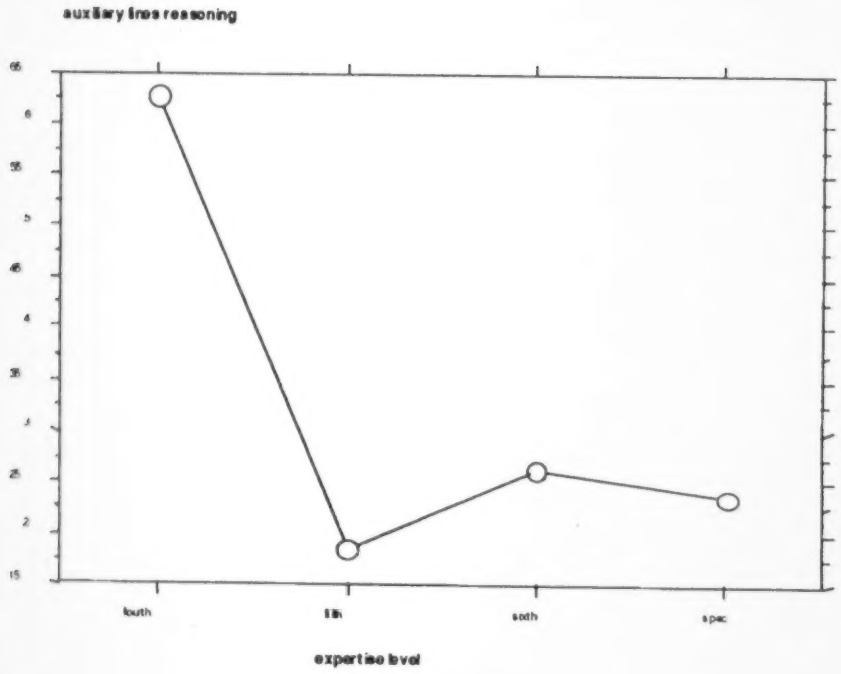

Figure 5. Number of auxiliary lines of reasoning

Table 2. Summary table of means and standard deviations of the five dependent variables per expertise level

	4th-year		5th-year		6th-year		specialists	
	Mean	sd	Mean	sd	Mean	sd	Mean	sd
diagnosis	1.085	*1.164*	1.336	*1.222*	2.093	*1.171*	2.941	*.243*
protocol length	54.898	*33.814*	35.234	*34.447*	42.163	*25.573*	37.941	*12.915*
N propositions	65.119	*45.936*	38.938	*41.534*	52.326	*40.235*	35.647	*18.960*
N biomedical Concepts	10.898	*18.705*	6.062	*5.939*	8.837	*6.466*	7.412	*5.397*
auxiliary reasoning	.627	*1.173*	.188	*.531*	.256	*.581*	.235	*.437*

Table 3. means and standard deviations of the proportion biomedical concepts in the think-aloud protocols per expertise level

	4th-year		5th-year		6th-year		specialists	
	Mean	sd	Mean	sd	Mean	sd	Mean	sd
prop. biomedical Concepts	.135	*.077*	.135	*.106*	.153	*.112*	.136	*.024*